Annual Technical Progress Report (End Year 2)

# Terrestrial Plasmasphere Feature Tracking and Volume Visualization via Tomographic Backprojection

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## 1  Introduction

This report summarizes the second-year progress for the AISRP award under grant NAG5-12109.

Our project involves development of techniques that can allow exploitation of IMAGE EUV data. Specifically, our project aims to develop tomographic backprojection techniques that allow reconstruction of the plasmsphere's plasma distribution from a time-series of the EUV images. A primary goal is to allow recovery of the equatorial-plane plasma distribution, and a secondary goal is to allow recovery of the plasma distribution throughout the plasmasphere. In addition, we aim to provide a community-accessible interface to our techniques and to provide tools that support tracking of plasmaspheric features in time-series of EUV data.

The plasmaspheric plasma distribution reconstruction problem is a challenging one because only a limited number of views of the plasmasphere can be used in a reconstruction. In particular, since only one EUV image is collected each 10 minutes and the plasmasphere is changing over time, it is advantageous to use as few images as possible for the reconstruction. Our approach to solving the reconstruction problem is via use of algebraic tomographic reconstruction techniques that use as few IMAGE EUV images as possible.

Algebraic reconstructions perform the reconstruction by solving a very large system of simultaneous equations with linear algebraic methods. Algebraic methods for tomographic reconstruction problems have commonly been used when the number of views is limited, as is the case in our problem. In the algebraic methods, the volume of space for which a distribution needs to be recovered is modeled as a set of cells. For each cell, the distribution is determined by the method.

## 2  Brief Progress Summary (Results to Date)

In this section, the progress on the project is briefly summarized. A brief background is given to help orient the reader, but to make this report a tractable length and to avoid what could be unnecessary duplication, many low-level details have been omitted.

### 2.1  Background

In the first year of the project, we primarily considered the effect on accuracy of the number of views and the resolution of the reconstruction. We also considered the effects of noise on reconstruction accuracy. Finally, we began exploring the impact of exploiting physical constraints in reconstruction. Our research in Year

One culminated in the demonstration that our volume-sampling approach to reconstruction could be more accurate than the conventional point-sampling approach [6].

## 2.2 Year Two Progress

In Year Two, our work primarily involved two foci: exploiting physical constraints to allow accurate reconstruction from a limited number of views and tracking plasmaspheric features using the active contours (snakes [3]).

### 2.2.1 Exploiting Physical Constraints

The first major undertaking in Year Two was exploration of the effects of exploiting physical constraints on reconstruction accuracy. Specifically, we initially investigated the impact of north-to-south symmetry exploitation. We also investigated exploiting an empirical model of plasmaspheric plasma distribution developed by Huang et al. [1] from an IMAGE RPI-based study.

The plasmasphere's plasma density is approximately symmetric about the equator, although at times other than the equinox, the density in one hemisphere about the geomagnetic equatorial plane can be as much as 10% higher than the density in the other hemisphere [1]. For time periods in which the plasma density is nearly symmetric about the equator, the plasma reconstruction process can be aided by exploitation of this physical constraint. In Year Two, we incorporated the capability to exploit such a constraint in our tomographic reconstruction methodology. For such times, the reconstruction need only solve for the distribution on one side of the equator; the cells on the other side of the equator have a symmetric distribution and need not be solved for explicitly. The equatorial symmetry constraint serves to thus approximately halve the number of unknowns via approximately doubling the number of samples. We have found that such an approach can improve the accuracy of reconstruction [4] by about 10% over standard reconstruction without exploiting physical constraints. Currently, we are building a web-accessible interface to our method to enable space science community use.

Huang et al.'s [1] recent study of plasmaspheric densities found that the density distribution along a field line can be reasonably well-modeled as a function of magnetic latitude and radial geocentric distance. In Year Two, we investigated how to exploit this model in volume reconstruction. This model essentially describes the plasma density at any location on a given field line as latitudinally varying. Exploitation of this model allowed us to further reduce the number of unknowns in the tomographic reconstruction. Essentially, exploitation of the model allows solution for only the equatorial plane's cells; the plasma densities in other cells can be determined by application of the latitudinal variation model. Incorporation of the latitudinal variation model into our reconstruction framework proved to be a little tricky, but eventually the model was incorporated. The impact on reconstruction accuracy from exploiting the Huang et al. model was also benchmarked. To establish a reliable baseline, the benchmark was performed for a known (i.e., synthetic) scenario. Incorporation of Huang et al.'s model was found to improve reconstruction accuracy about threefold over standard reconstruction without exploiting physical constraints.

### 2.2.2 Feature Tracking

The second major undertaking in Year Two was development of a new snake-based method to track the boundary of the plasmasphere in a time-series of EUV images. The method can potentially allow study of change in the plasmapause, including the evolution of plasmapause boundary features over time. This method is described in a paper that will appear at the 2004 International Conference on Pattern Recognition (ICPR) [2]. The snake-based method uses a template of a representative EUV image to position the snake near the center of an EUV image. Then, the snake is inflated. The inflation process uses image features,
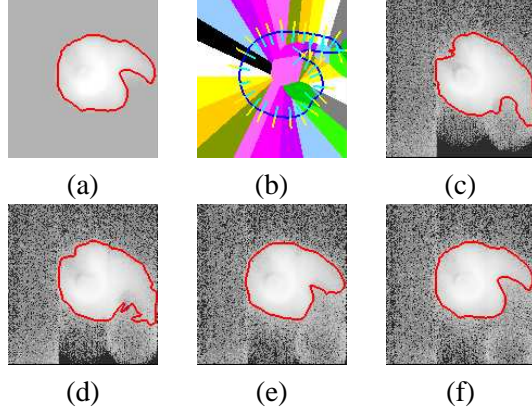
Figure 1: (a) Snake after constrained evolution. (b) Voronoi diagram for a snake. (c – f) Snake on a time-series sequence of EUV images, (c) $20^{th}$ frame, (d) $25^{th}$ frame, (e) $30^{th}$ frame, (f) $35^{th}$ frame.

especially high gradient points, to attract the snake toward the plasmapause, which is typically characterized by a sudden decrease in plasma density. The attraction process also uses a Voronoi diagram to prevent the snake inflation process from creating loops (i.e., self-intersections in the boundary). The new snake-based plasmapause tracking method exhibits good accuracy—on the order of 1 pixel average error from a manually-traced plasmapause boundary.

Figure 1, which is taken from the ICPR paper [2], demonstrates the performance of our snake-based plasmapause tracking for one image sequence.

# 3   Plans for Year Three

The third year of the project will primarily involve integrating the developed tools and methods into a web-based interface that can be easily used by members of the space sciences community. We will also continue to explore refinement to our physical constraint- based schemes for improving the accuracy of reconstruction in our limited-angle scenario. In particular, we plan to incorporate a co-rotation model that corrects for the effects of the plasma co-rotating with the Earth over the time that a set of views are collected. In addition, we plan to make our feature tracking approach available via web access to the community. The approach will run in both stand-alone mode and coupled with the tomographic reconstruction. (In the latter mode, the approach will be used to detect the plasmapause boundary. The reconstruction process can utilize that information to focus the plasma reconstruction on the region of space within the plasmasphere, which will reduce the number of unknowns in the algebraic formulation thus increasing the determinism of the system of equations). Finally, we plan to extend our work in 2D plasmaspheric feature tracking to tracking of features in 3D.

# 4   Contributions to Education

In Year Two, a number of graduate students worked with the senior researchers on the project.

The primary student supported by the project this year was Naveen Santhanam. Mr. Santhanam is currently finishing up his Masters thesis; he expects to defend in early June. His research work on the project has primarily focused on methods that exploit physical constraints about the plasmasphere to improve reconstruction accuracy. Mr. Santhanam was co-author of one recent paper ([4]) arising out of the project.

A second student, Cuilan Wang, began work on the project in January 2004. Ms. Wang is a new Ph.D. student at the University. She has worked on plasmapause boundary detection and is incorporating knowledge of that boundary into the reconstruction scheme to allow further improvement in reconstruction accuracy. She is also assisting in the effort to build the integrated web-based tool for plasmasphere volume reconstruction.

A third student, Ram Kandimalla, has been working on down-stream processing issues, primarily related to tracking of plasmapause features over time via a new snake-based [3] mechanism. Mr. Kandimalla is a Ph.D. student who was supported on a part-time basis by the project in the past year. Currently, he is not compensated by the project; he works as a teacher in the instructional unit and on his own time on our project due to his high interest in the topic. He is co-author of one recently-accepted paper ([2]) arising out of the project.

Other students who have made contributions to the work in the past year include Ph.D. student Huijuan "Jean" Zhang. Since Ms. Zhang participated in early work on the project, she was able to offer start-up pointers to new students, such as Ms. Wang. Ms. Zhang defended her dissertation in early 2004 and is now transitioning out of the University. Her AISRP-funded research efforts (which validated our volume-sampling approach and established baseline performance expectations for reconstruction performance as the number of views increased) were a significant part of her dissertation ([5]).

We believe that the achievement of educational objectives is one beneficial outcome of this research project. Our research effort is thus both achieving technical objectives as well as improving human capital.

# 5   End Notes

Although the project officially started in April 2002, we did not really begin research efforts in depth until Summer 2002. We are within reasonable range of completing our goals for the second year of the project and should be very close to the year two target by the end of the twenty-fourth month of earnest effort on the project.

# References

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